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ABSTRACT

This training unit on fire behavior is part of a 17-unit course package written to aid instructions in the development, teaching, and evaluation of fire fighters in the Wisconsin Fire Service Certification Series. The purpose stated for the 8.5-hour unit is to assist fire fighters in gaining an understanding of fire behavior--chemistry of the fire, flame spread, flashover, phases of burning, classes of fire, heat transfer, and extinguishing agents. An instructor's guide sheet provides this information: introduction to the topic, instructor preparation, length of unit, methods of instruction, testing, equipment and facilities required, recommended visual aids, and references. Following a list of unit objectives, a lesson plan outlines the main teaching points and states the preferred teaching method, cites the reference and page number(s) where the information is to be found, and indicates the necessary handouts. Other contents in the unit include a unit quiz, answer key to the quiz, and handouts (graphs, student worksheets, informational material, and forms). (YLB)

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FIRE SERVICE CERTIFICATION SERIES

UNIT FSCS-FF-3-80

FIRE BEHAVIOR

FIRE SERVICE TRAINING

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WISCONSIN FIRE SERVICE TRAINING
INSTRUCTOR'S GUIDE SHEET

CODE: FSCS-FF-3-80
1-A

FIRE BEHAVIOR

Prepeared by:

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Fire Service Training

INTRODUCTION

This unit has been developed to assist the fire fighter in gaining an understanding of fire behavior.

The unit includes the chemistry of fire, flame spread. flashover, phases of burning, classes of fire, heat transfer and extinguishing agents.

The purpose of this unit is to provide a base from which the firefighters can increase their knowledge and understanding of the material and methods taught in the entire course.

INSTRUCTOR PREPARATION

Carefully study the objectives to determine the goals that have been set for the firefighters upon completion of the unit.

Review the lesson plans and if necessary, consult the references listed.

Develop suitable audio-visual aids, provide training area and necessary tools and equipment to effectively teach this unit.

LENGTH OF UNIT

Classroom Work and Demonstration	8 hours
Evaluation and Testing	30 minutes

METHOD OF INSTRUCTION

Illustration and Demonstration

Suggested methods and techniques are listed under Instructors Notes on the lesson plan. For further information consult Fire Service Instructor Training, IFSTA #303 3rd ed., pp. 71-83.

Also see list of suggested demonstrations at the end of this unit.

OBJECTIVES

All objectives in this unit are to be met according to the material contained in the International Fire Service Training Association Manuals #101 Forecible Entry, Rope and Extinguisher Practices, #107 Fire Ventilation Practices, #200 Essentials of Fire Fighting, #201 Fire Service Practices for Volunteer Fire Departments and #303 Fire Service Instructor Training.

To satisfactorily complete this unit, the firefighter must attain a grade of 70 or higher on the written quiz.

NFPA STANDARD 1001

FIRE BEHAVIOR

FIRE FIGHTER I

3-16 Fire Behavior

3-16.1 The firefighter shall demonstrate the knowledge of fire behavior including the chemistry of fire, flame sread, flashover, phases of burning, classes of fire and heat transfer.

FIRE FIGHTER II

4-18 Fire Behavior

4-18.1 The firefighter shall demonstrate the knowledge of fire suppression agents.

COURSE: FIRE SERVICE CERTIFICATION SERIES

LESSON: FIRE BEHAVIOR

EQUIPMENT NEEDED: DEMONSTRATION EQUIPMENT (SEE APPENDIX)

TRAINING AIDS: AUDIO-VISUAL EQUIPMENT, SLIDES, TRANSPARENCIES, TEXTS

INSTRUCTORS NOTES	TEACHING POINTS
Ref: IFSTA #107 Ventilation 5 th ed., p. 11, Essentials of Fire Fighting, 1st ed., p. 3, #201 Volunteer 5th ed., pp. 172-173	Fire Behavior Fire is a chemical reaction known as combustion. It is frequently defined as the RAPID OXIDATION OF COMBUSTIBLE MATERIAL ACCOMPANIED BY A RELEASE OF ENERGY IN THE FORM OF HEAT AND LIGHT.
Refer to Fig. 1 Handout #1	Fire Triangle The three sided fire triangle illustrates that oxygen, heat and fuel in proper proportions create a fire. If any one of these three elements is removed a fire cannot exist
3-16 Fire Behavior 3-16.1	Fire Tetrahedron In recent years, many new chemical and materials have been produced which will burn and react in a manner which cannot be explained completely by the use of the fire triangle.
Ref. IFSTA #107 Ventilation p. 12	Some questions which defy explanation under this theory are: Why will calcium and aluminum burn in a nitrogen atmosphere in the absence of oxygen ? Why do some fuels burn more rapidly when subjected to radioactive emenations ? Why do flame react with certian sonic vibrations and electrically charge particles ? There have been several theories advanced which answer some of these questions and the one most generally accepted in the "Fire Tetrahedron Thoery".

INSTRUCTORS NOTES

TEACHING POINTS

Those who developed this theory made a transition, from the plane geometric triangular figure, which we recognize as the fire triangle, to a four-sided solid geometric figure which resembles a pyramid.

Ref: IFSTA #107 Ventilation pp. 12-13, #200 Essentials of Fire Fighting pp. 4-6

The fourth, or base side, of the figure represents the CHEMICAL CHAIN REACTION.

Refer to Fig. 2 Handout #2

The three standing sides represent:

HEAT
FUEL
OXYGEN

Refer to Fig. 3 Handout #3

The removal of one or more of the four sides will make the tetrahedron incomplete and result in extinguishment of the fire.

The theory has not done away with the fire triangle. It has simply added a fourth component or condition.

Ref: IFSTA #107 Ventilation, p. 14, #201 Volunteers, p. 173, #200 Essentials of Fire Fighting p. 3

FUEL (Reducing Agent)

The fuel side for both the triangle and the tetrahedron is the same and is defined as:

MATERIAL THAT CAN BE OXIDIZED

The term "reducing agent" refers to the fact that fuel reduces an oxidizing agent.

PHYSICAL STATE

Solids
Liquids
Gases

Ref. #107 p. 16
#200 p. 5
#201 p. 175

OXYGEN (Oxidizing Agent)

The term "oxidizing agent" explains how some materials (which release their own oxygen under certain conditions) can burn in an atmosphere free of any outside source of oxygen.

Some examples of oxidizing agents are:

Oxygen	Nitric Acid
Hydrogen Peroxide	Sulfuric Acid
Fluorine	Manganese Dioxide
Chlorine	Lead Dioxide
Bromine	Nitrates
Chromates	Chlorates

INSTRUCTORS NOTES

TEACHING POINTS

HEAT (Temperature)

Heat and temperature are closely related and in some cases inseperable. Heat is a type of energy in disorder while temperature is a measure of the degree of that disorder.

CHEMICAL CHAIN REACTION

To have a fire there must be:

FUEL-HEAT-OXYGEN

Ref: #107 p. 16
#200 p. 5
#201 p. 175

Refer to Fig. 4
Handout #4

The following steps occur simultaneously in varying degrees of instensity without flame.

The fuel must be heated to give off gases and vapors and sufficient heat must be present to ignite these vapors.

When either liquid or solid fuels are burning, the vapors which are distilled off and carried into the flame, contain atoms or molecules which have not been consumed in the initial burning process.

These atoms and radicals are released from fragmented molecules.

New compounds are formed by the released radicals forming with other atoms.

This process is continously repeated with oxygen and other atoms being drawn into the flame area.

The heat and light associated with fire is produced by these repeated reactions.

The three methods of fire suppression:

(1) Remove the fuel
(2) Exclude the oxygen
(3) Reduce the temperature

have grown to four methods with the addition of:

(4) stop the chain reaction

INSTRUCTORS NOTES | TEACHING POINTS

Ref; Fire Protection Handbook 14th ed., p. 3-19

FLAMMABLE LIQUID CHARACTERISTICS

Liquids which burn are divided into two types:

Flammable and Combustible

FLAMMABLE LIQUIDS - are those with a flashpoint below 100 Degrees F. (37.8 C.)

COMBUSTIBLE LIQUIDS - are those with a flashpoint at or above 100 Degrees F. (37.8 C.)

IFTSA #107 p. 17

FLASH POINT is the lowest temperature at which a material will give off vapors in sufficient quanity to ignite momentarily.

Refer to Fig. 5 Handout #5

See Demonstration #4

The amount of vapor which a material evolves is governed by the temperature of the material.

An increase in temperature causes a proportionate increase in vapor.

The reverse is true in reducing temperature and vapor.

Below the flash point temperature, vapors cease to exist in quantities which may be ignited.

Ref: #107 pp. 18

FIRE OR BURNING POINT-at a certain temperature, normally a few degrees above the flash point, a material will emit sufficient quantities of vapors to ignite and continue to burn.

Refer to Fig. 6 Handout #5

See Demonstration #4

The temperature at which a material will give off vapors rapidly enough to sustain combustion is known as the burning or fire point.

IGNITION TEMPERATURE AND SOURCES

Ref: #107 pp. 18-20

The term "ignition temperature" refers to two specific things:

1. The minimum temperature required to ignite a material.

Refer to Fig. 7 Handout #5

See Demonstration #5

2. The temperature at which a material will ignite spontaneously independent of an outside ignition source. This is also referred to as "Autoignition Temperature".

Ignition may occur as a result of:

Open flame	Friction	
Arcing/sparking	Chemical reaction	
Spontaneous heating	Adiabatic Compression	Hypergolic liquids

INSTRUCTORS NOTES

TEACHING POINTS

HYPERGOLIC MIXTURES are certain fuels and oxidizers which are used in combination as propellants for some missles and rockets.

Hypergolic liquids will ignite on contact with each other without an ignition source.

Mixtures of fuels and oxidizers that do nor react or ignite when combined are called AMERGOLS.

ADIABATIC COMPRESSION is a term used to describe the generation of heat when a liquid or gas is compressed.

If a flammable mixture is compressed rapidly, heat produced by the compression may be sufficient to raise the temperature of the mixture to its ignition point.

Ref: IFSTA #107 Ventilation 5th ed., pp. 19-20

SPONTANEOUS HEATING

To cause spontaneous heating a substance must be easily oxidized.

If the material is stored in a condined space so that air circulation cannot carry away the heat, oxidation continues to build up heat which in turn creates more heat increasing the rate of oxidation until the ignition temperature of the material is reached.

An important aspect of spontaneous heating is that the substance must be a poor conductor of heat or it must be adequately insulated to prevent the escape of heat.

Materials subject to spontaneous heating may be classified as:

(1) Noncombustible materials which react with other substances to produce sufficient heat to ignite adjacent combustibles, e.g., a combination of unslaked lime and water.

(2) Substances having ignition temperatures below ordinary temperatures, such as phosphorus.

(3) Combustible substances which may undergo sufficient oxidation at ordinary temperatures to reach their ignition temperature, such as oily rags or soft coal.

(4) Organic combustible substances subject to biochemical reactions, such as poorly cured hay and grain.

INSTRUCTORS NOTES	TEACHING POINTS
	EXPLOSIVE RANGE LIMITS
	In the mixture of flammable vapors with air there exists:
	LOWER LIMIT - in which traces of the vapor may be found in the air, but not in sufficient quantities to ignite.
	UPPER LIMIT - Beyond which the concentration of vapors has excluded oxygen to the extent that ignition is not possible.
Refer to Fig. 8 Handout #6 See Demonstration #6	EXPLOSIVE RANGE - the range of vapor mixture which will ignite when subjected to an ignition source. Also referred to as the ignitable mixture.
	VAPOR DENSITY - refers to the weight of vapor compared to air.
Refer to Fig. 9 Handout #7 See Demonstration #8 See Demonstration #7	Air is used as a medium of measurement and is given the weight of 1. Thus any gas or vapor which weighs more than 1 is heavier than air. SPECIFIC GRAVITY - refers to the ratio of the weight of a solid or liquid substance to the weight of an equal volume of water. The specific gravity of water is 1.
	PRODUCTS OF COMBUSTION
Ref: IFSTA #107 Ventilation 5th ed., pp. 19-24	When a fuel burns it undergoes chemical change and there are four products of combustion: (1) fire gases - carbon monoxide - carbon dioxide (2) flame (3) heat (4) smoke FIRE GASES - are the vaporized products of combustion. Most common combustibles contain carbon which when burned form carbon monoxide (CO) and carbon dioxide (CO2) The types of fire gases that will be formed during a fire are determined by: The chemical composition of the fuel The percent of oxygen present for combustion and The temperature of the fire.

INSTRUCTORS NOTES

TEACHING POINTS

Ref: IFSTA #107 Ventilation 5th ed., p. 22

Refer to Fig. 10
Handout #8

The carbon in most fuels can be burned to complete combustion under controlled conditions. An example of this is the burning of methane (natural gas) in heating or cooking equipment.

COMPLETE COMBUSTION

Methane CH_4 + Oxygen $2O_2$ ⟶ Carbon Dioxide CO_2 + Water $2H_2O$

INCOMPLETE COMBUSTION

Methane CH_4 + Oxygen O_2 ⟶ Carbon Monoxide CO + Water H_2O + H_2

Under most burning conditions such as fires, the oxygen concentration is seldom adequate for complete combustion.

This situation is particularly true with carbon fuels other than methane, such as:

- wood
- cloth
- paper
- hydrocarbons

When only a part of the carbon is oxidized CARBON MONOXIDE instead of carbon dioxide is formed.

Carbon monoxide is unstable and has such an affinity for oxygen that it will combine with or rob any other oxygen-bearing substance of its oxygen to form carbon dioxide (CO_2).

Carbon monoxide heated to 1200 degrees F. in the presence of oxygen will burn to produce CO_2. It is:

- colorless
- tasteless
- odorless
- slightly lighter than air
- and DANGEROUS

It may be formed by slow oxidation or may be found in:

- sewers
- caves
- wells
- mines
- automobile exhaust
- stoves
- furnaces

Hydrogen Sulfide (H_2S) is a fire gas which may be formed during fires involving organic material containing sulfur such as:

hair-wool-meat-hides

INSTRUCTORS NOTES

TEACHING POINTS

Hydrogen Sulfide

It is:

colorless
has a strong "rotten egg" odor
heavier than air
will ignite at 500 degrees F.
DANGEROUS AND TOXIC

Nitrous fumes or oxides of nitrogen are also common fire gases and are DANGEROUS-POISONOUS

Ref: IFSTA #107 Ventilation 5th ed., pp. 24-25

FLAME - is the visible luminous body of a burning gas, which becomes hotter when it is mixed with increased amounts of oxygen.

However heat, smoke and gas can develop in certain types of smouldering fires without evidence of flame.

HEAT - is a form of energy which is measured in degrees of temperature to signify its intensity.

Heat is that product of combustion which is responsible for the spread of fire.

In addition to burns, it is responsible for heat-related injuries including:

dehydration - heat exhuation - injuries to respiratory system.

Heat combined with oxygem depletion and carbon monoxide formation are regarded as the primary hazards in a fire.

SMOKE -

Smoke ordinarily encountered at a fire consists of a mixture of oxygen, nitrogen, carbon dioxide, some carbon monoxide, finely divided particles of soot and carbon and a miscellaneous assortment of products which have been released from the material involved.

Ref: IFSTA #107 Ventilation 5th ed., pp. 25-33

PHASES OF BURNING

Refer to Fig. 11 Handout #9

Incipient or 1st Phase

In the first phase, the oxygen content has not been significantly reduced and the fire is producing:

Water Vapor (H_2O)
Carbon Dioxide (CO_2)
Carbon Monoxide (CO)
Sulfur Dioxide (SO_2
and other gases

INSTRUCTORS NOTES	TEACHING POINTS
	PHASES OF BURNING
	Incipient or first phase
	Oxygen level approximately 20%
	The fire may be producing a flame temperature of well above 1000 degrees F., yet the temperature in the room at this stage may be only slightly increased.
	Free Burning or 2nd Phase
	The second phase of bruning encompasses all of the free burning activities of the fire.
Refer to Fig. 12 Handout #10	Oxygen rich air is drawn into the flame as convection carries the heat to the uppermost regions of the confinement area.
	Heated gases spread out laterally from the top downward, forcing the cooler air to seek lower levels and eventually igniting all the combustible material in the upper levels of the room.
	Oxygen level between 15 and 20%
	CAUTION in this situation, firefighters must keep low, one breath of this superheated air can sear the respiratory tract as the temperature in the upper regions can exceed 1300 degrees F.
	Smouldering or 3rd Phase
Refer to Fig. 13 Handout #11	In the third and final phase, flame may cease to exist if the area of confinement is sufficiently airtight.
	Burning is reduced to glowing embers.
	Room becomes completely filled with fire gases and dense smoke to the extent that enough pressure is built up to force them to seep from cracks and openings in the building.
	Oxygen level below 15%
	The fire will continue to smoulder filling the room with dense smoke and gases of combustion at a temperature well over 1000 degrees F.
	The intense heat will have vaporized the lighter fuel fractions, such as hydrogen and methane, from the combustible material.

INSTRUCTORS NOTES

TEACHING POINTS

Smouldering or 3rd Phase

These fuel gases will be added to those produced by the fire and will further increase the hazard.

DANGER - BACKDRAFT OR SMOKE EXPLOSION POSSIBLE

Refer to Fig. 15
Handout #12

FLASHOVER

Is a stage of fire when a room or other area becomes heated to the point where flames flashover the entire surface of the area.

The cause of flashover is attributed to the excessive buildup of heat from the fire itself.

As the fire continues to burn, all the contents of the fire area are gradually heated to their ignition temperature.

When they reach this point, simultaneous ignition occurs and the area becomes fully involved in fire.

Ref: IFSTA #200 Essentials of Fire Fighting 1st ed., p. 8

FLAME SPREAD

Is the rate at which flame travels over the surface.

Interior building materials and finishes have a flame spread rating which indicates the relative rate at which flame will spread over the surface of the material.

The lowest rating is zero (0) which idicates no flame spread.

The higher the number, the faster the spread of flame.

These numbers are the results of tests conducted by various approved testing agencies.

FIRE EXTINGUISHING METHODS

There are four basic methods of accomplishing this:

(1) remove the fuel
(2) exclude the oxygen
(3) reduce the temperature
(4) stop the chain reaction

REMOVAL OF FUEL

The removal of fuel to extinguish fire is effective but not always practical or possible.

INSTRUCTORS NOTES

TEACHING POINTS

REMOVAL OF FUEL

Methods of fuel removal include:

(1) turning off the fuel supply
(2) pumping flammable liquids from a burning tank
(3) removing unburned portions of solid combutibles from coal piles or silos
(4) diluting liquid material that is burning

Water can be used to dilute ethyl alcohol which is water soluble.

Emulsifying agents can be used to dilute flammable liquids which are not water soluble as it will mix with the top layer of the flammable liquid and stop vaporization.

AFFF surface active agents can contain flammable vapors removing fuel from combustion areas.

Flammable gases can also be diluted and can become noncombustible with the addition of an inert gas such as carbon dioxide or nitrogen.

EXCLUSION OF OXYGEN

Smothering or blanketing will extinguish fires by separating oxygen from heat and fuel.

Example: placing a lid over a pan of flaming grease on the stove.

In some cases fires cannot be extinguished by smothering-

Some plastics, such as cellilose nitrate, and some metals such as titanium, cannot be extinguished by smothering because they do not depend on an external air supply.

REDUCTION OF TEMPERATURE

One widely used method of fire extinguishment is cooling and quenching.

Temperature control involves the absorbtion of heat with a resultant cooling of the fuel to a point at which it ceases to release enough vapors to maintain a flammable vapor.

Heat is carried away from a fire by radiation, conduction and convection as well as by absorbtion by a cooling agent.

16

OF ALL THE EXTINGUISHING AGENTS, WATER ABSORBS MORE HEAT PERVOLUME THAN ANY OTHER AGENT.

INSTRUCTORS NOTES

TEACHING POINTS

INHIBITION OF CHAIN REACTION

This last method of extinguishment is the inhibition of the chain reactions which occur in the combustion process.

Formation and consumption of certain atoms are the key to the chain reaction which produces the flame.

Certain chemical substances have the ability to break up this reaction.

When introduced into the fire in the proper amounts these substances inhibit the atoms which the flame needs to keep burning. Without the reaction the flame cannot continue to burn and the fire is extinguished.

Some examples of these agents are:

Halon 1301
Halon 1211
Halon 2402
Sodium Bicarbonate (regular dry chemical)
Potassium Bicarbonate (Purple K)
Potassium Carbonate (Monex)
Potassium Chloride (Super K)

CLASSIFICATION OF FIRES

Class A Fires

Fires involving ordinary combustibles such as:

wood
cloth
paper
rubbish
and may platics

Class B Fires

Fires involving flammable liquids, greases, oils and gases such as:

gasoline
paints
thinners
oils
grease
lacquers
LP-gas

Class C Fires

Fires involving energized electrical equipment

INSTRUCTORS NOTES

TEACHING POINTS

Class D Fires

Fires in combustible metals such as:

Magnesium — Titanium
Zirconium — Sodium
Potassium

Ref: IFSTA #107 Ventilation 5th ed., pp. 33-37 #200 Essentials of Firefighting 1st ed., pp. 10-11, #201 Volunteer, 5th ed., p. 182

HEAT TRANSFER

Heat can travel thru a burning building by one or more of four methods:

(1) conduction
(2) Radiation
(3) convection
(4) direct flame contact

Since heat is disordered energy, it never remains constant but is continually transferred from objects of higher temperature to those of lower temperatures.

The colder of two bodies in contact will absorb heat until both objects are the same temperature.

Refer to Fig. 16 Handout #13

CONDUCTION

Heat may be conducted from one body to another by direct contact of the two bodies or by an intervening heat-conduction medium.

The amount of heat transferred and its rate of travel by this method depends upon the conductivity of the material through which the heat is passing.

Not all materials have the same heat conductivity.

Aluminum, copper and iron are good conductors -

Stone, wood, felt, cloth and paper are poor conductors -

Liquids, gases and air are poor conductors because of the rapid movement of their molecules.

Refer to Fig. 17 Handout #13

RADIATION

This method of heat transmission is known as radiation of heat waves.

Heat and light waves are similar in nature but they differ in length.

Heat waves are longer than light waves and they are sometimes called infrared waves.

INSTRUCTORS NOTES

TEACHING POINTS

RADIATION

Radiated heat will travel thru space until it reaches an opaque object, as the object is exposed to heat radiation it will radiate heat from its surface.

Radiated heat is one of the major sources of fire spread and its importance demands an immediate defensive attack at points where radiation exposure is severe.

Refer to Fig. 18
Handout #14

CONVECTION

Convection is the transfer of heat by air or liquid.

Heated air will expand, become lighter and move upward.

As the heated air moves upward, cooler air takes its place at lower levels.

The spread of fire by convection has more influence on positions for fire attack and ventilation then either conduction or radiation.

Refer to Fig. 19
Handout #14

DIRECT FLAME CONTACT

Fire also spreads along and thru a material that will burn by direct flame contact.

When a substance is heated to a point where flammable vapors are given off, these vapors may be ignited.

Any other flammable material which is in contact with the burning vapors may be heated to a temperature where it will ignite and burn.

Ref: IFSTA #107 Ventilation 5th ed., pp. 82-84

EXTENSION OF FIRE - throughout a structure occurs in diffrenet ways such as:

Refer to Fig. 34
Handout #15

Through stairwells, elevators and shafts by direct flame contact or by convected air currents;

Through partitions and walls and upward between walls by flame contact and convected air currents;

Refer to Fig. 42-B-54
Handout #16-17

Through windows and other outside openings where flame extends to other exterior openings and enters upper floors.

Through ceilings and floors by conduction of heat thru beams, pipes or other objects that extend from floor t floor;

INSTRUCTORS NOTES

TEACHING POINTS

EXTENSION OF FIRE

Through ceilings and floors by direct flame contact;

Through floor and ceiling openings where sparks and burning materials fall thru to lower floors and

By collapse of floors and roofs.

Ref: IFSTA #107 Ventilation pp. 37-38, #105 Fire Streams pp. 10-14

THE LAW OF SPECIFIC HEAT

From a fire protection standpoint, specific heat is a measure of the heat absorbing capacity of a substance.

Refer to Fig. 20
Handout #18

Water is noncombustible but can absorb a large amount of heat.

The quantity or amount of heat is measured in terms of British Thermal Units (Btu's).

A British Thermal Unit (Btu) is the amount of heat neede to raise the temperature of one pound of water one degree farenheit at or near its maximum density (39.1 degrees F.) as illustrated in Fig. 20.

SPECIFIC HEAT is the ratio between the amount of heat necessary to raise the temperature of a specific quantity of a material and the amount of heat necessary to raise the temperature of an identical quantity of water by the same number of degrees.

Air is chosen as a standard in comparing vapor weights and water is chosen as the standard against which other substances are comparde.

THE SPECIFIC HEAT OF WATER IS 1.0. The specific heat of diffrent substances varies.

The speed by which one substance absorbs heat from another is increased in proportion to the surface exposed to heat,

This principle also applys to water in a liquid state. If water is divided into many drops the rate of heat absorbtion will be increased hundreds of times.

The application of the Law of Specific Heat to fire streams enables one to understand why the finely divided particles of water of a fog stream will absorb heat more rapidly than will a solid stream.

INSTRUCTORS NOTES

TEACHING POINTS

THE LAW OF LATENT HEAT OF VAPORIZATION

Latent Heat of Vaporization is the quantity of heat absorbed by a substance when it changes from a liquid to a vapor.

At sea level, water boils at 212 degrees F., at this temperature it vaporizes and turns to steam.

The vaporization, however, does not happen at the instant the water reaches the boiling point.

Each pound of water will require approximately 970 Btu's of additional heat to completely turn it into steam.

This characteristic is significant in fighting fire, for the temperature of the water is not increased beyond 212 degrees farenheit during the absorbtion of the 970 Btu's for every pound of water.

Refer to Fig. 21-A
Handout #19

Refer to Fig. 21-B
Handout #20

A gallon of water at 70 degrees F., will therefore, absorb more than 9,000 Btu's of heat if all the water is converted to steam.

The formula is:

212 degrees - 70 degrees = 142 degrees; specific heat = 1 degree farenheit per pound

1 gallon of water = 8.33 pounds

Therefore 142 x 8.33 = 1183

and 970 x 8.33 = 8080

then 1183 + 8080 = 9263 Btu's

The discharge of a 100 gpm fog nozzles into a highly heated room area will absorb approximately 926,000 Btu's of heat per minute.

INSTRUCTORS NOTES

TEACHING POINTS

Some of the quantities of Btu's produced by different fuels are:

1 pound of coal	10,000 Btu's
1 pound of wood	8,000 Btu's
L gallon of gasoline	130,000 Btu's

The quantity of heat that may be produced by a combustible object depends on the material from which it is compunded.

The rate at which the material gives off this heat depends on conditions such as:

its physical form
amount of surface exposed
air supply

EXPANSION OF GASES

Gases have no definite form or volume.

This property of gases is due to the very rapid molecular motion and an almost complete lack of cohesion (clinging together).

Ref. to Fig. 22
HANDOUT #21

When a contained gas is heated, its molecular motion is accelerated and consequently, the pressure within the container is greatly increased.

Gases expand more than either liquids or solids when heat is applied.

The expansion of some gases is approximately nine (9) times that of water, and the rate of expansion is very nearly the same for all gases.

Certain flammable gases will expand so greatly that, when they are ignited an explosion results.

INSTRUCTORS NOTES

TEACHING POINTS

4-18 Fire Behavior

4-18.1

Ref: IFSTA #101 Extinguishers 6th ed., pp.156-157

EXTINGUISHING AGENTS

A. Water

1. Extinguishment principles
   a. remove heat/lower ignition temperatures
   b. flame disengagement
2. Classes water can be used on
   a. Class A
   b. Class B - certain instances
3. Physical characteristics
   a. freezes at 32 degrees F. 0 degrees C.
   b. boils at 212 degrees F. 100 degrees C.
   c. weighs 8.33 pounds per gallon
   d. noncompressible
   e. high surface tension
   f. takes shape of container
   g. needs expellant force in most cases
4. Advantages
   a. absorbs a large amount of heat
   b. plentiful
   c. can be used with special agents
5. Limitations
   a. conductor of electricity
   b. high surface tension
   c. freezes
   d. reacts with certain chemicals
   e. weight

INSTRUCTORS NOTES

TEACHING POINTS

B. Carbon Dioxide

1. Extinguishment principle

   a. remove/displace oxygen by weight of CO2 gas

2. Classes CO2 can be used on

   a. Class A - special instances

   b. Class B

   c. Class C

3. Physical characteristics

   a. normally a gas

   b. liquified under temperature and pressure

   c. 1½ times heavier than air

   d. low temperature 110 degrees F. when solid

4. Advantages

   a. high expansion ratio

      1 pound liquid converts to 8 cu. ft. of free gas

   b. readily turns from liquid to gas

   c. provides its own pressure

   d. nonconductor

5. limitations

   a. slightly toxic

   b. water soluble

   c. cannot be used on class A without special adaptation

INSTRUCTORS NOTES

TEACHING POINTS

C. Halogenated Hydrocarbons (Halons)

1. Extinguishment principle

a. break chain reaction

b. some cooling

Classes Halon can be used on

a. Class A - special instances

b. Class B

c. Class C

3. Physical Characteristics

a. liquid under pressure

b. 2½ times as effective as CO2

4. Advantages

a. high expansion ratio

b. provides own pressure

c. nonconductor

5. Limitation

a. slightly toxic

D. Dry Chemicals

1. Extinguishment principle

a. break chain reaction

b. some cooling

2. Classes dry chemical can be used on

a. Class A

b. Class B

c. Class C

INSTRUCTORS NOTES

TEACHING POINTS

D. Dry Chemicals

3. Physical Characteristics

a. Several base chemicals

(1) sodium bicarbonate - ordinary

(2) potassium bicarbonate - purple K

(3) potassium chloride - super K

(4) Urea-potassium bicarbonate - monex

(5) monammonium phosphate - multi-purpose tri-class A-B-C.

b. Additives for free-flowing and water repulsion.

c. Finely ground powder

d. Needs expellant force

4. Advantages

a. Many applications

b. Large fire knock-down potential

c. Nonconductor

d. Some dry chemicals are foam compatible

5. Limitations

a. Can become packed

b. Cannot interchange chemicals

c. Large concentrations can cause difficulties in seeing and breathing

d. No cooling -- hot metal may re-ignite flammable liquids

e. Some dry chemicals are corrosive

f. Some dry chemicals form coatings

INSTRUCTORS NOTES

TEACHING POINTS

E. Dry Powders

1. Extinguishing principle

   a. Remove oxygen

2. Class dry powders can be used on

   a. Class D

   b. examples:

      (1) Magnesium - Lithium

      (2) Zirconium - Hafnium

      (3) Potassium - Plutonium

      (4) Titanium - Uranium

      (5) Sodium

3. Physical Characteristics

   a. Fine powder

   b. Needs expellant force

4. Advantages

   a. Can control some types of Class D Fires

   b. The extremely high temperature of some burning metals makes water and other common extinguishing agents ineffective.

   c. No one agent will effectively control fires in all combustible metals

   d. Special extinguishing agents for control of fires in EACH of the metals must be used.

      Such As:

   e. G-1 Powder - Magnesium, sodium, potassium, lithium titanium, zirconium, hafnium, thorium uranium and plutonium

   f. Met-L-X Powder - Magnesium, sodium (spills or in depth) potassium, sodium potassium alloy

INSTRUCTORS NOTES

TEACHING POINTS

F. Wetting Agents (Wet Water)

1. Extinguishing principle

a. Same as water

2. Uses

a. Increase extinguishing efficiency of water by

(1) Decrease surface tension

(2) Aids penetration

(3) Decrease run-off

3. Methods of adding to water

a. Pre-mixed for booster tanks

b. Proportioning equipment

4. Advantage

a. Cuts down amount of water used

b. Reduces overhaul time

5. Limitations

a. Agent can freeze

b. Corrosive with certain materials

G. Fire Fighting Foam

1. Uses

a. Class A, special applications

b. Class B

2. Physical characteristics

a. Mass of gas filled bubbles

b. Lighter than the solutions it is formed from

c. Floats on flammable liquids

d. Produces air-excluding, cooling, vapor sealing, water bearing solution

INSTRUCTORS NOTES

TEACHING POINTS

G. Fire Fighting Foam

3. Types and characteristics

a. Protein foaming agent

(1) Liquid concentrate and proportioning

(a) Proportioning

i) 3% 97 gallons of water 3 gallons foam

ii) 6% 94 gallons of water 6 gallons foam

(b) Aeration

i) Hand held nozzle with vents

ii) At nozzle

(2) Manufactured from natural protein solids

(3) Normal use temperatures from 20 degrees F to 120 degrees F.

(4) Sticks to objects

b. Aqueous Film Forming Foam (A Triple F)

(1) Liquid concentrate and proportioning 3% or 6%

(2) Manufactured from synthetics

(3) Forms film capable of self-sealing after disruption

(4) May be used with some dry chemicals

c. High Expansion Foam

(1) Liquid concentrate and proportioning 2%

(2) Manufactured from synthetics

(3) Expansion ratios from 100x to 1000x

(4) Flooding agent used for confined spaces

(5) Manufactured by passing air through a net or screen that is wetted with the foa solution

INSTRUCTORS NOTES

TEACHING POINTS

G. Fire Fighting Foam

c. High Expansion Foam

(6) Engine powered or hand-held units are available

d. Other Foams

(1) Chemical

i) Aluminum sulfate

ii) Sodium bicarbonate

iii) Not used much anymore

(2) Alcohol type

(3) Low temperature

e. Rapid Water

(1) Agent designed to reduce friction loss

(2) Increases delivery of gallons per minute

(3) Increases reach of streams

(4) 1 gallon additive per 6000 gallons of water increases the flow 40%

UNIT QUIZ

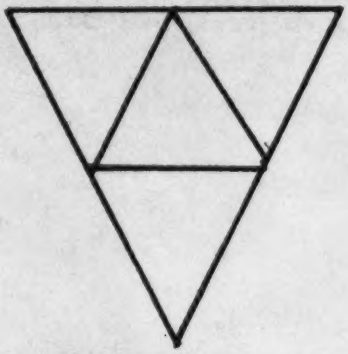
1. Name the three sides of the Fire Triangle

   a._____

   b._____

   c._____

2. Label the faces of the Fire Tetrahedron shown below



3. In order for flaming combustion to take place, an oxygen content of at least_____ to _____% must be present in the air.

4. In order for free burning or flaming combustion to take place, there must be what amount of oxygen present.

   (Circle the letter in front of the correct answer)

   a. 20-21% c. 10-14%

   b. 15-16% d. 6-8%

5. List the four classes of fire

   a._____

   b._____

   c._____

   d._____

6. Which of the following definitions is correct for the term flash Point ?

(Circle the letter in front of the correct answer)

a. the lowest temperature at which a solid or liquid will give off enough vapors to ignite momentarily.

b. the lowest temperature at which a solid or liquid will give off enough vapors to ignite and burn.

c. the point at which vapor pressure equals atmospheric pressure.

d. the lowest amount of gas and vapor which when mixed with air will burn or explode.

7. A Class A Fire involves which of the following fuel catagories ?

(Circle letter in front of correct answer)

a. energized electrical equipment

b. flammable metals

c. flammable liquids

d. ordinary combustibles

8. List the three phases of fire by names other than first, second and third.

a._____

b._____

c._____

9. Heat which is transferred from one object to another by an intervening material is said to have been transferred by:

(Circle letter in front of the correct answer)

a. convection

b. radiation

c. direct flame contact

d. conduction

10. According to the Tetrahedron of Fire, there are four means by which a fire may may be extingusihed. List these methods.

    1._____

    2._____

    3._____

    4._____

11. List three basic by-products of combustion common to almost all fires.

    1._____

    2._____

    3._____

12. Flammable liquids have a flash point of:

    (Circle letter in front of the correct answer)

    a. 50 degrees F. or less

    b. 140 degrees F. or less

    c. 100 degrees F. or less

    d. 130 degrees F. or less

13. Heat which is transferred by the movement of liquid or air, is said to have been transferred by:

    Circle letter in front of correct answer)

    a. convection

    b. direct flame contact

    c. radiation

    d. conduction

14. During the second or free burning phase of a fire, the ceiling temperature may be expected to reach:

    (Circle letter in front of correct -nswer)

    a. Approximately 1300 degrees F.

    b. Approximately 100 Degrees F.

    c. Over 1500 degrees F.

    d. 2000 degrees F.

15. The term specific gravity is best defined by which of the following ?

(Circle letter in front of the correct answer)

a. the weight of vapor or gas compared to air

b. the atmospheric pressure measured at sea level

c. the point at which liquid boils

d. the weight of a liquid compared to water

16. When there is more than 21% oxygen in the air, fires will burn_____ than usual.

17. As the oxygen content of air is increased, burning becomes:

(Circle letter in front of correct answer)

a. more difficult

b. possible, but at a slower rate

c. more rapid

d. impossible

18. In general, the smaller the piece of fuel:

(Circle letter in front of correct answer)

a. the easier it ignites, but it burns more slowly

b. the easier it ignites and the more rapidly it burns

c. the slower it ignites, it burns more rapidly

d. the slower it ignites, the slower it burns

19. During the third or smouldering phase of a fire the oxygen content will have fallen to about:

(Circle letter in front of correct answer)

a. less than 15%

b. Between 20 and 21%

c. 15 to 19%

d. over 21%

20. List the four basic methods of heat transfer in a fire:

1. _____

2. _____

3. _____

4. _____

ANSWER KEY

1. Oxygen
   Fuel
   Heat

2. Oxygen
   Fuel
   Heat
   Chemical Chain Reaction

3. 15-16%

4. b.

5. Class A
   Class B
   Class C
   Class D

6. a.

7. a.

8. Incipient
   Free Burning
   Smouldering

9. d.

10. Oxygen control or smothering
    Fuel control or removal
    Heat removal or cooling
    Inhibition of chain reaction

11. water vapor
    smoke
    carbon dioxide
    carbon monoxide

12. 100 degrees F. or less

13. a.

14. a.

15. d.

16. faster-more rapidly

17. c.

18. b.

19. a

20. Convection
    Conduction
    Radiation
    Direct flame contact

THE FIRE TRIANGLE

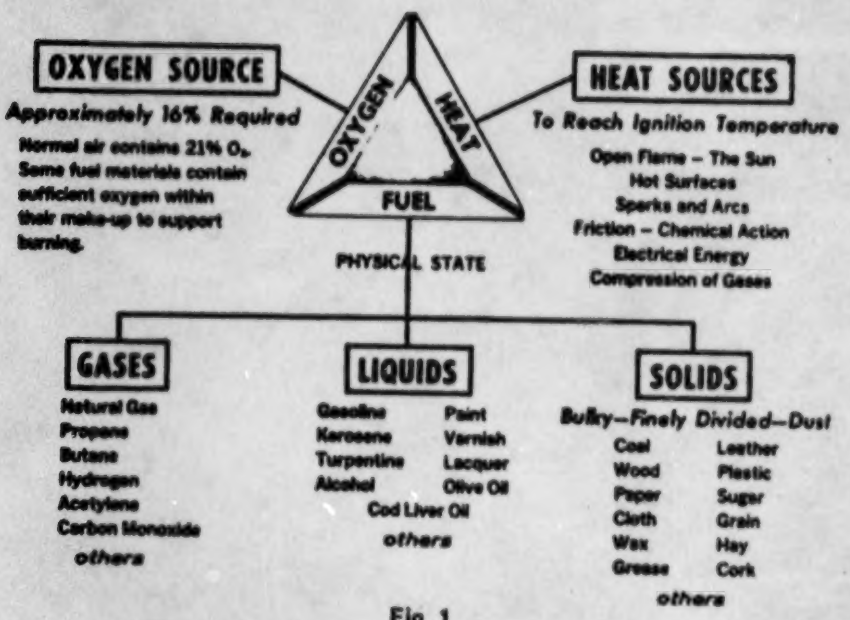


Fig. 1

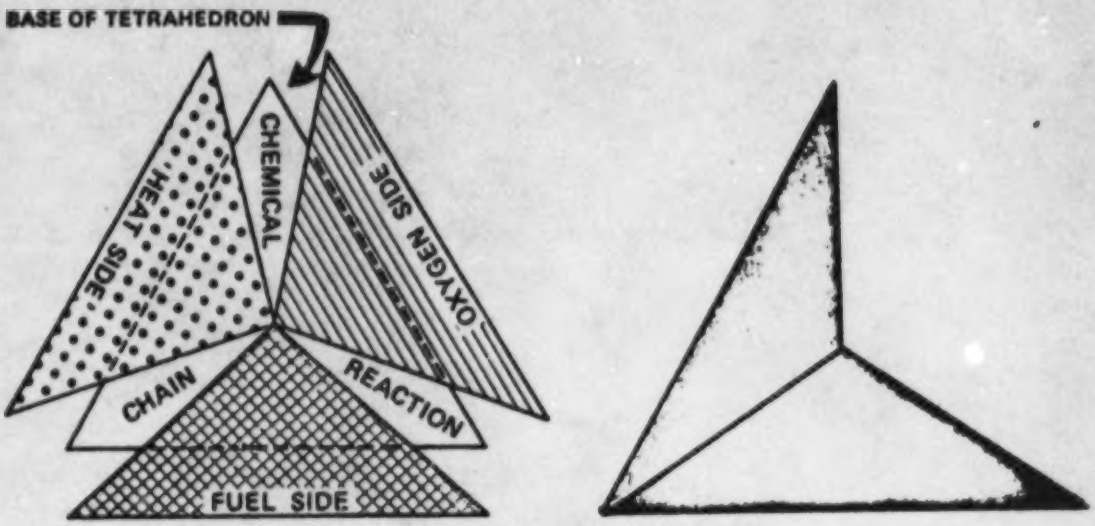

BASE OF TETRAHEDRON
HEAT SIDE
CHEMICAL
OXYGEN SIDE
CHAIN
REACTION
FUEL SIDE

Fig. 2

Fig. 2

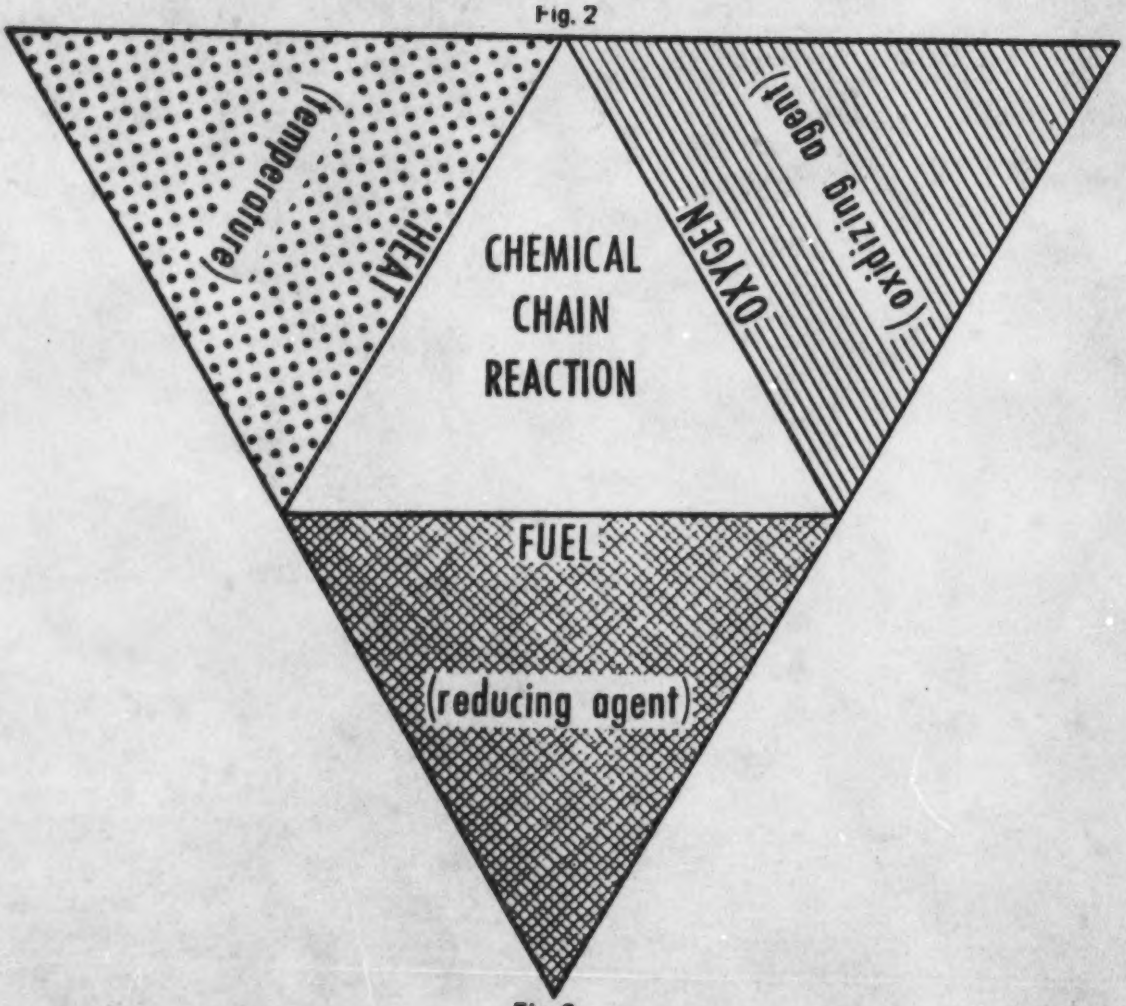
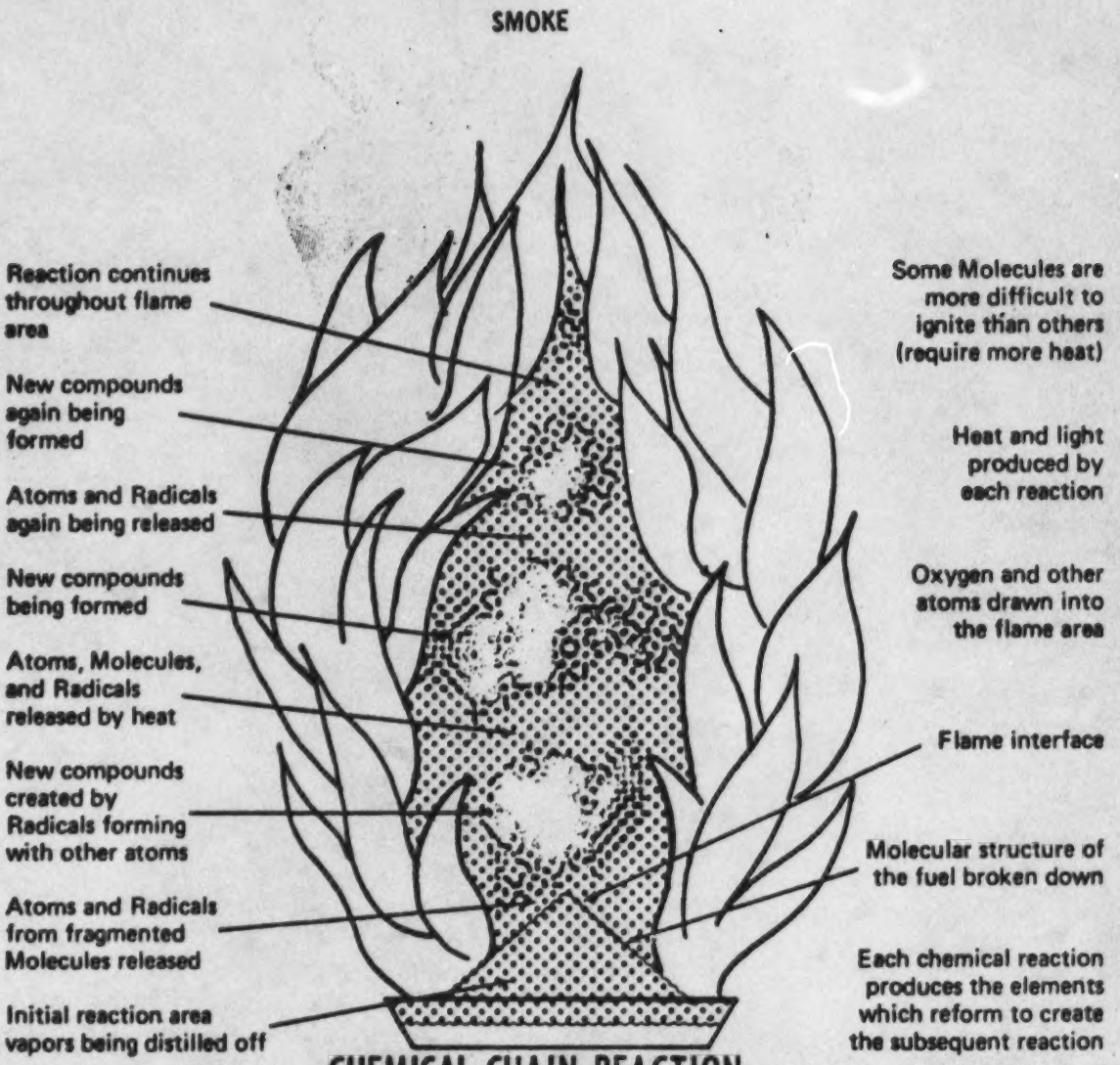
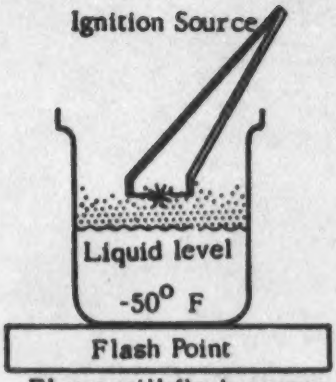

HEAT
(temperature)
OXYGEN
(oxidizing agent)
CHEMICAL
CHAIN
REACTION
FUEL
(reducing agent)

Fig. 3


SMOKE
Reaction continues throughout flame area
New compounds again being formed
Atoms and Radicals again being released
New compounds being formed
Atoms, Molecules, and Radicals released by heat
New compounds created by Radicals forming with other atoms
Atoms and Radicals from fragmented Molecules released
Initial reaction area vapors being distilled off
Some Molecules are more difficult to ignite than others (require more heat)
Heat and light produced by each reaction
Oxygen and other atoms drawn into the flame area
Flame interface
Molecular structure of the fuel broken down
Each chemical reaction produces the elements which reform to create the subsequent reaction

CHEMICAL CHAIN REACTION

Fig. 4

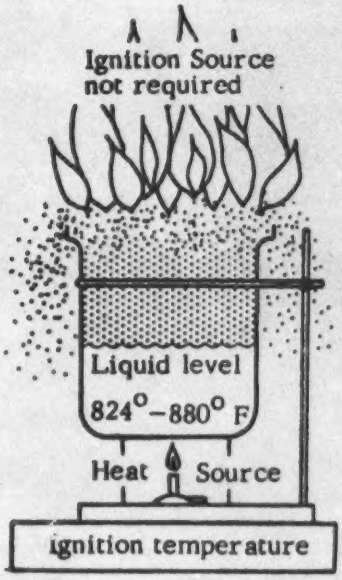


Flame will flash across the surface but will not continue to burn.

Fig. 5

Vapors are being evolved rapidly enough to sustain combustion.

Fig. 6



Substance has been ignited from self-contained heat

Fig. 7

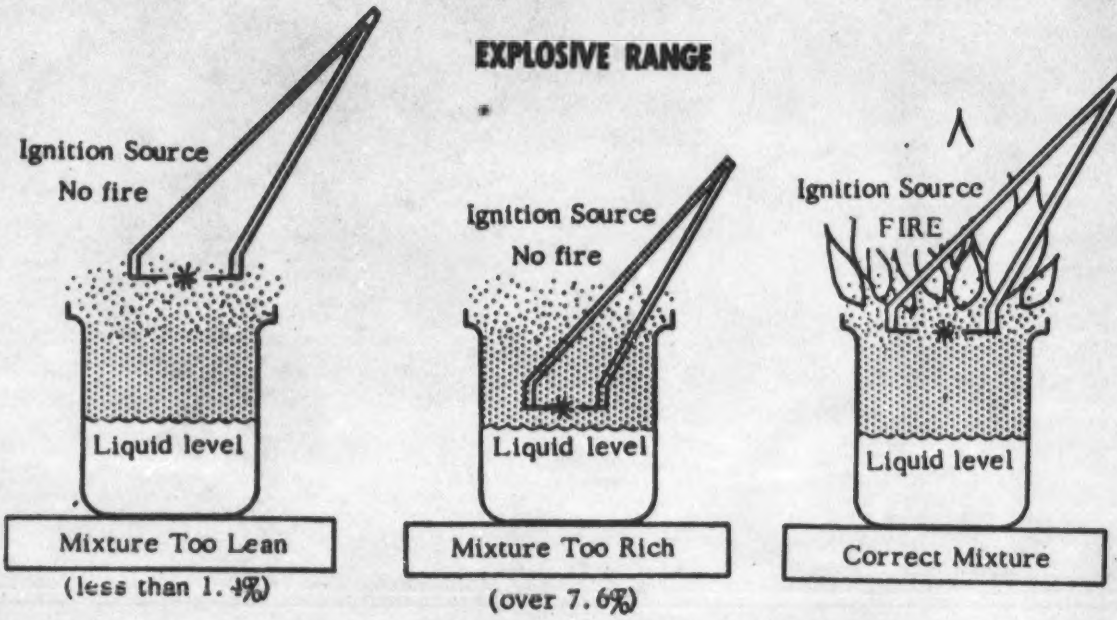
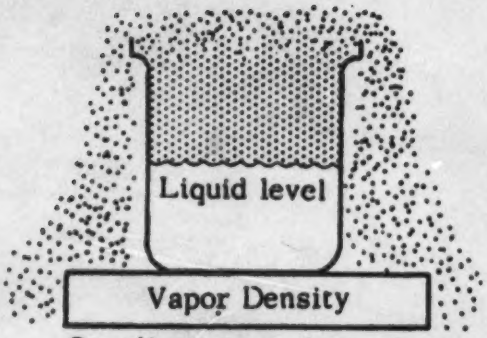

EXPLOSIVE RANGE
Ignition Source
No fire
Liquid level
Mixture Too Lean
(less than 1.4%)
Ignition Source
No fire
Liquid level
Mixture Too Rich
(over 7.6%)
Ignition Source
FIRE
Liquid level
Correct Mixture

Fig. 8



Gasoline vapor, being 3-4 times heavier than air, flows to the lowest point.

Fig. 9

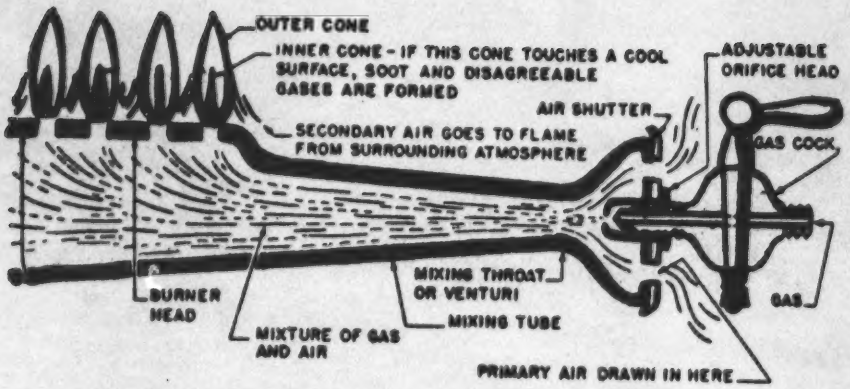
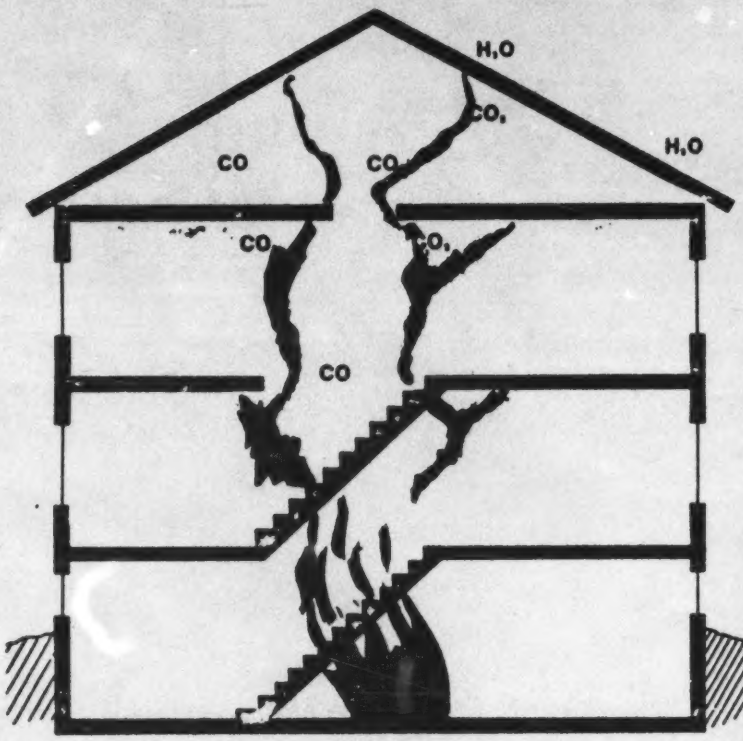
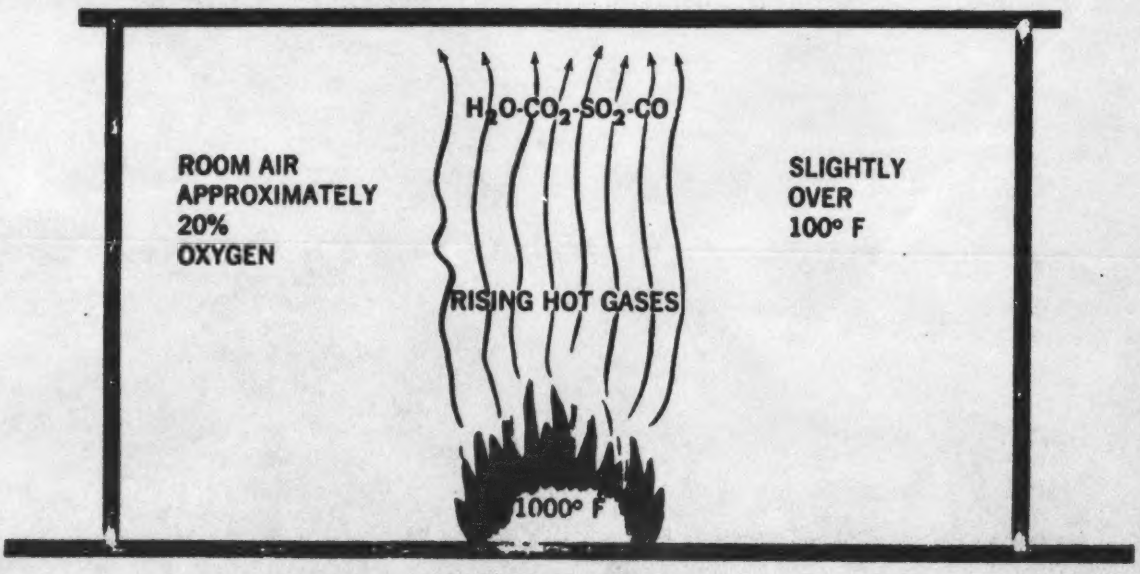

OUTER CONE
INNER CONE - IF THIS CONE TOUCHES A COOL SURFACE, SOOT AND DISAGREEABLE GASES ARE FORMED
SECONDARY AIR GOES TO FLAME FROM SURROUNDING ATMOSPHERE
ADJUSTABLE ORIFICE HEAD
AIR SHUTTER
GAS COCK
BURNER HEAD
MIXTURE OF GAS AND AIR
MIXING THROAT OR VENTURI
MIXING TUBE
GAS
PRIMARY AIR DRAWN IN HERE

Fig. 10

FIRST PHASE



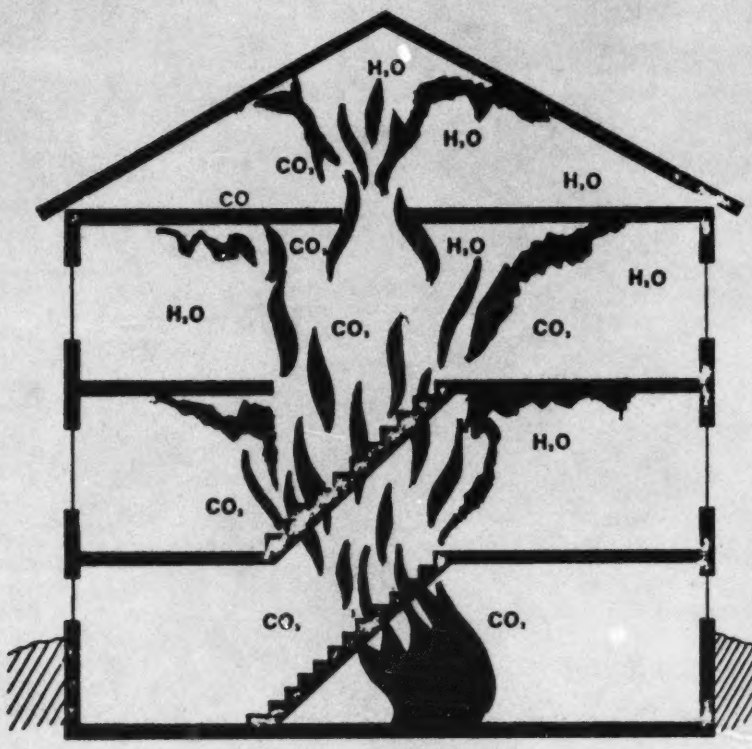
- FREE BURNING FIRE
- OXYGEN PLENTIFUL
- TEMPERATURE HAS NOT BUILT TO HIGH PEAK
- THERMAL UPDRAFT RISES, ACCUMULATES AT HIGHEST POINT
- BREATHING NOT DIFFICULT
- FIRE EXTINGUISHMENT: DIRECT APPLICATION OF WATER AT BASE OF FIRE
- VENTILATION: NOT A PROBLEM
- LITTLE STEAM PRODUCTION



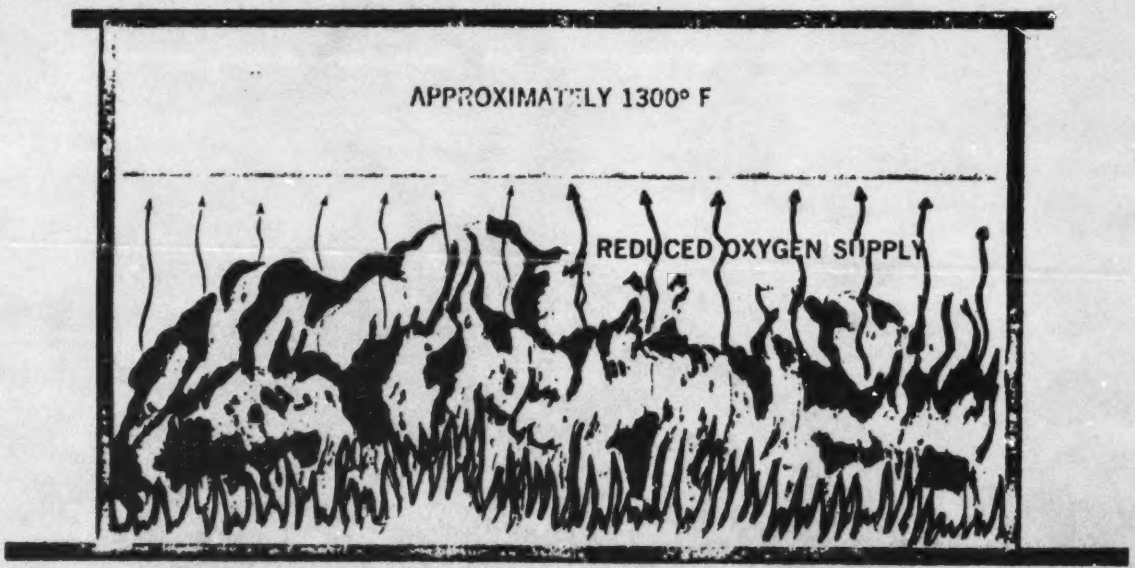
INCIPIENT PHASE

Fig. 11

SECOND PHASE



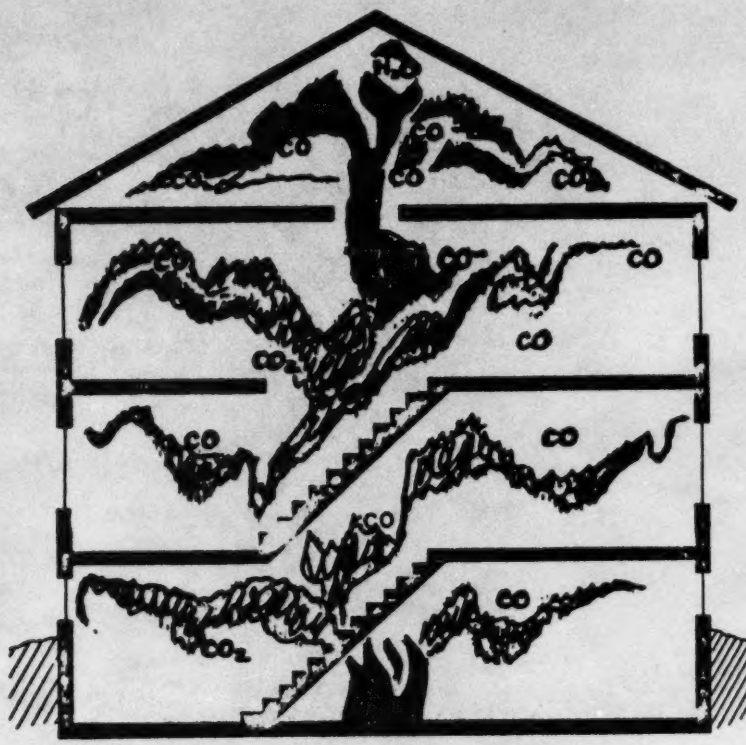
- FIRE HAS INVOLVED MORE FUEL
- OXYGEN SUPPLY IS BEING DEPLETED
- HEAT ACCUMULATES AT UPPER AREAS
- BREATHING DIFFICULT: MASKS RECOMMENDED
- FIRE EXTINGUISHMENT IS REACHING THE AREA OF MAJOR INVOLVEMENT
- VENTILIATION: NOT A DEFINITE NEED
- GOOD STEAM PRODUCTION



FREE BURNING PHASE

Fig. 12

THIRD PHASE


CO
CO
CO

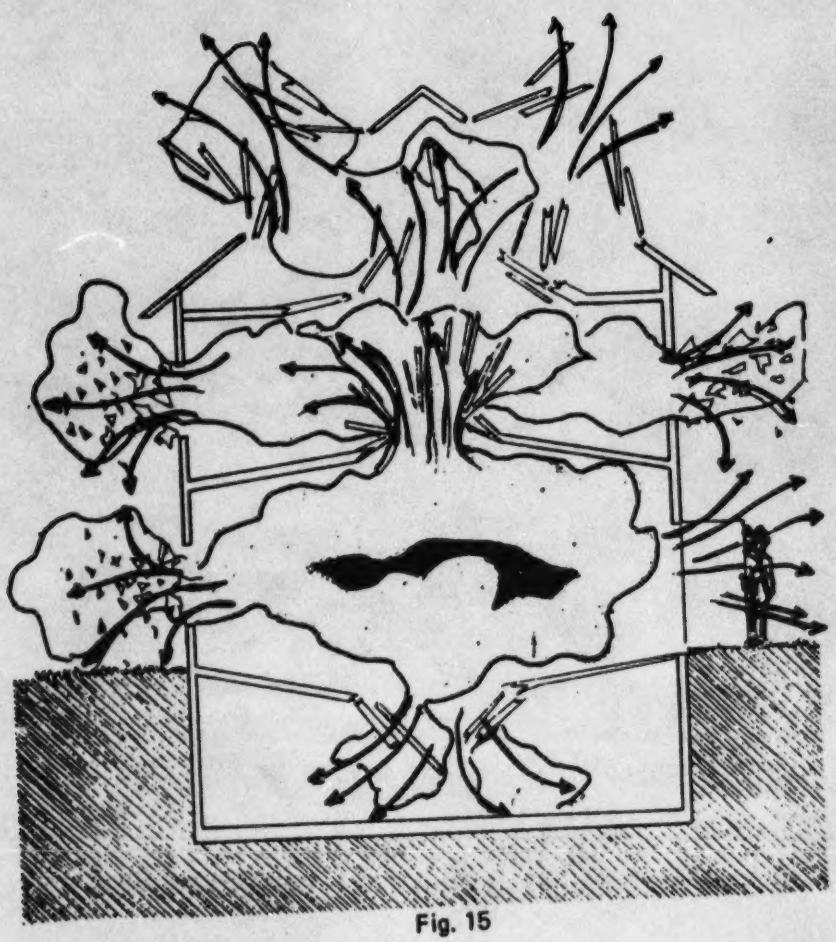


Fig. 15

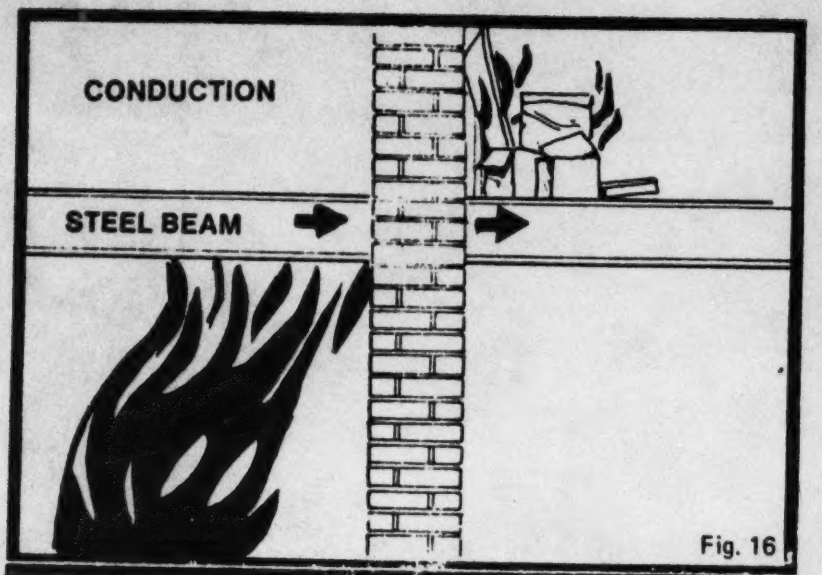


Fig. 16

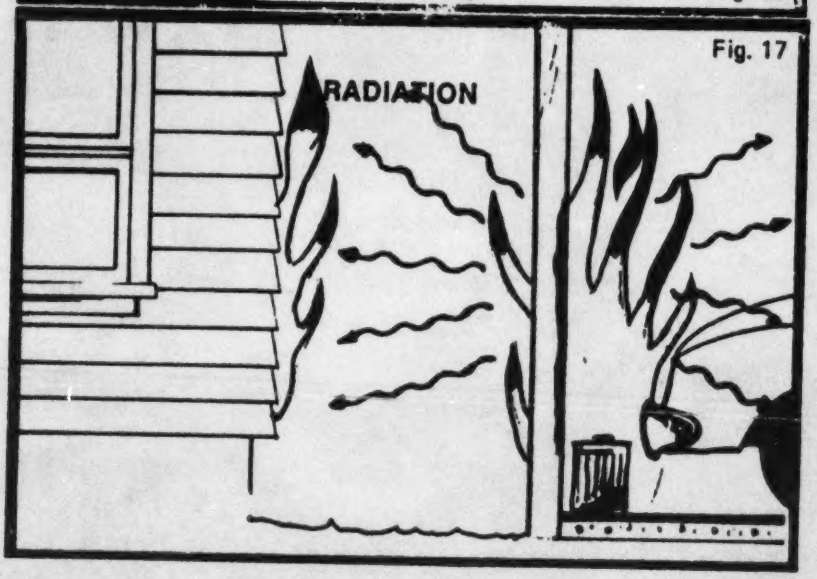


Fig. 17

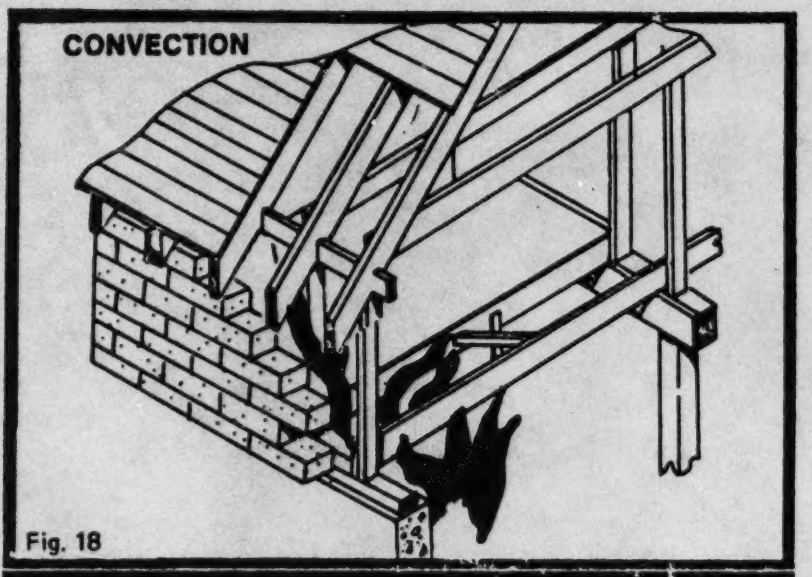
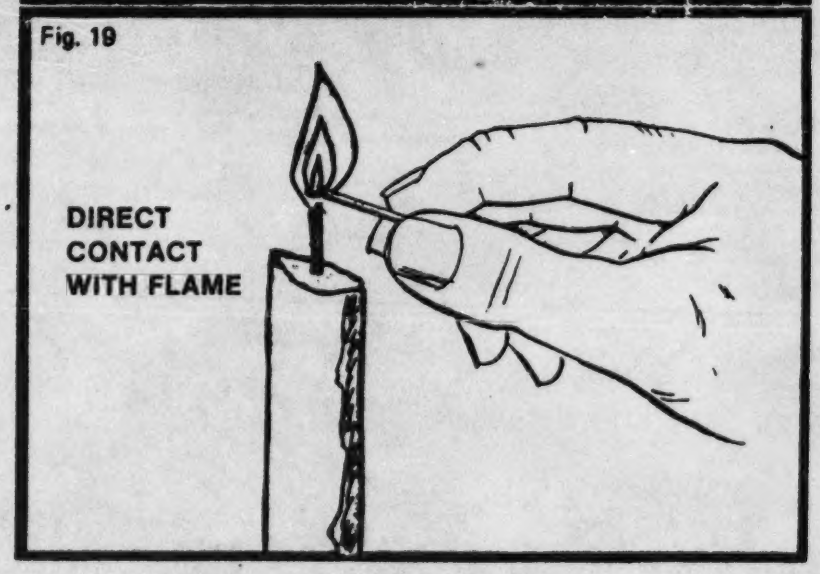
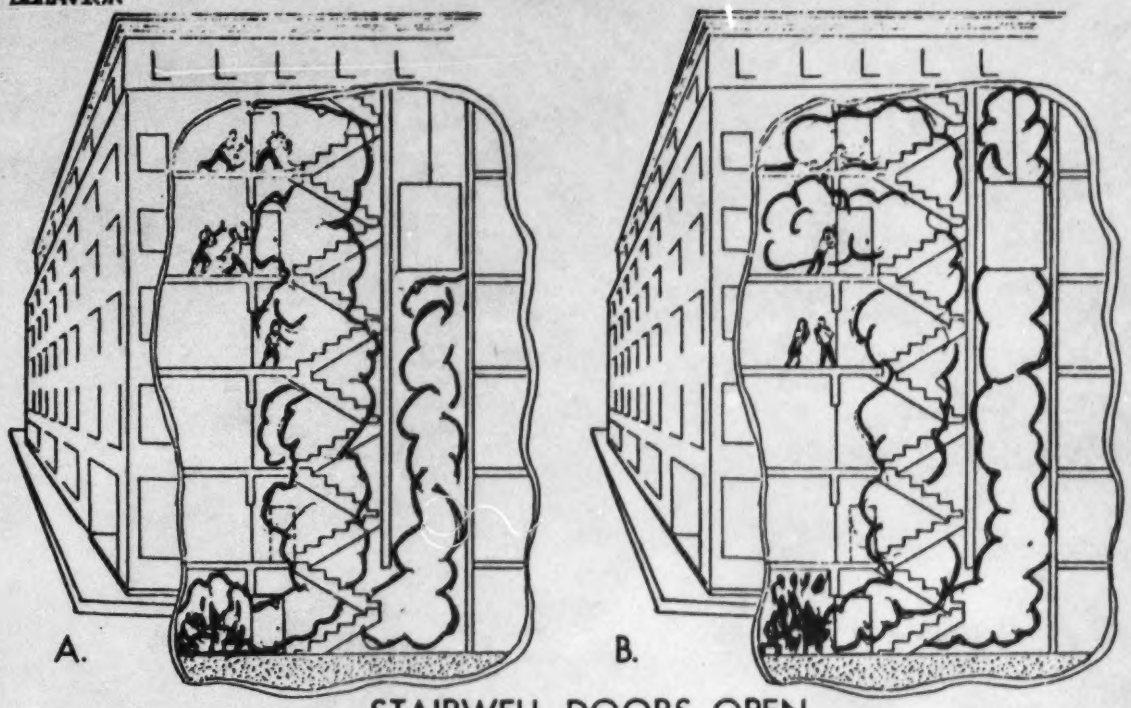


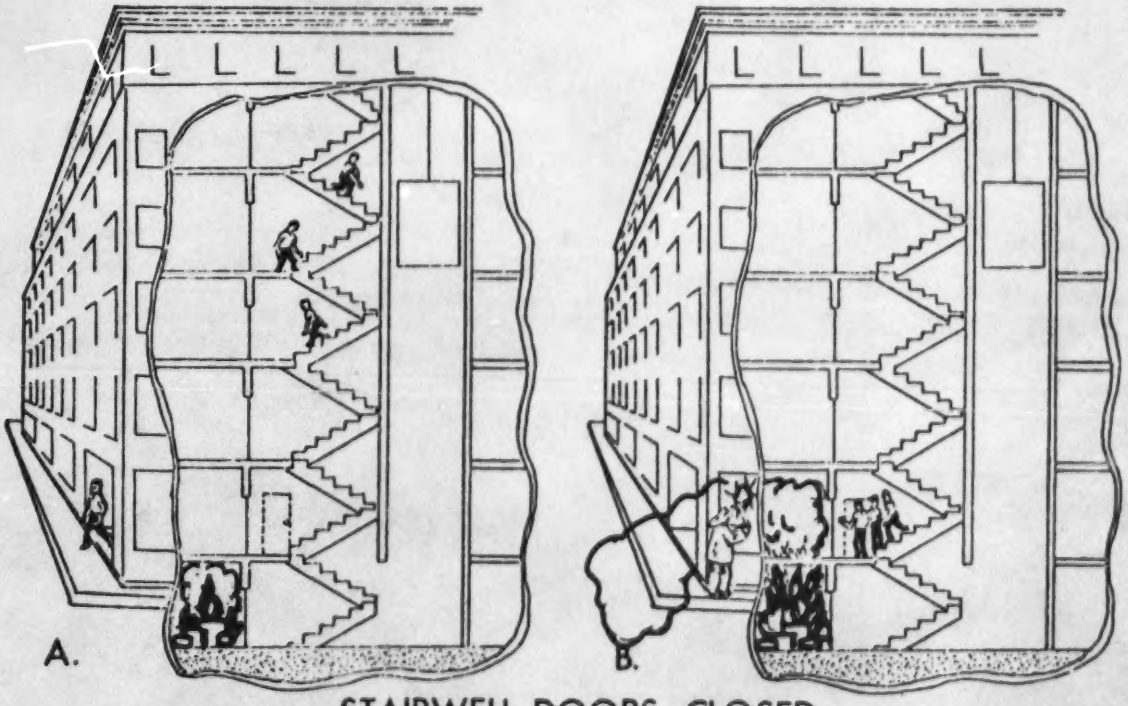
Fig. 18

Fig. 19





STAIRWELL DOORS OPEN



STAIRWELL DOORS CLOSED

Fig. 34

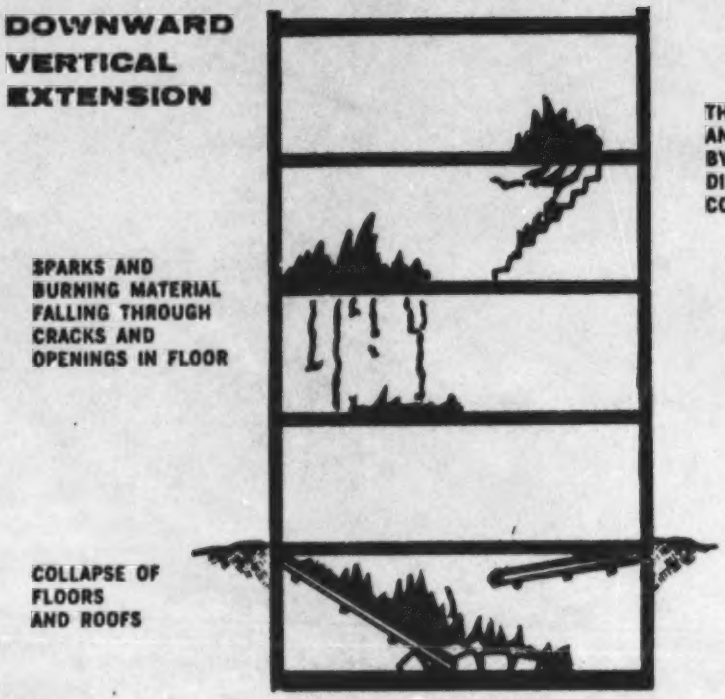

DOWNWARD
VERTICAL
EXTENSION
THROUGH FLOORS
AND CEILINGS
BY
DIRECT FLAME
CONTACT
SPARKS AND
BURNING MATERIAL
FALLING THROUGH
CRACKS AND
OPENINGS IN FLOOR
COLLAPSE OF
FLOORS
AND ROOFS

Fig. 42 B

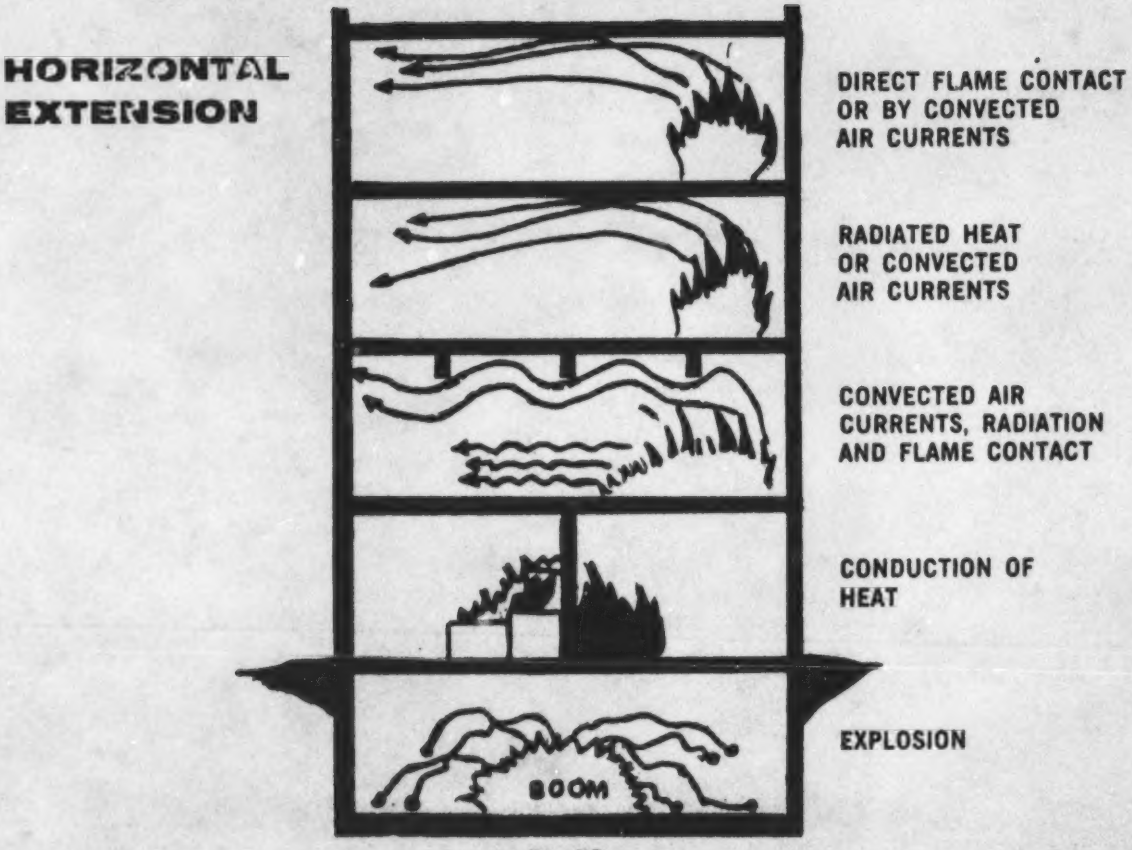

HORIZONTAL EXTENSION
DIRECT FLAME CONTACT OR BY CONVECTED AIR CURRENTS
RADIATED HEAT OR CONVECTED AIR CURRENTS
CONVECTED AIR CURRENTS, RADIATION AND FLAME CONTACT
CONDUCTION OF HEAT
EXPLOSION
BOOM

Fig. 53

THE LAW OF SPECIFIC HEAT

SPECIFIC HEAT:

- MEASURE OF THE HEAT ABSORBING OF A SUBSTANCE AS MEASURED IN BRITISH THERMAL UNITS (BTU'S) OR IN HEAT CALORIES
- INDICATES THE RELATIVE QUANTITY OF HEAT REQUIRED TO RAISE TEMPERATURES TO DANGER POINT, OR HOW MUCH HEAT MUST BE REMOVED TO COOL A SUBSTANCE TO A SAFE TEMPERATURE

BRITISH THERMAL UNIT

- AMOUNT OF HEAT REQUIRED TO RAISE 1 LB. OF WATER 1° FAHRENHEIT

CALORIE

- Calorie (Kilogram or Large Calorie) = amount of heat required to raise the temperature of one kilogram of water one degree centigrade
- calorie (gram or small calorie) = amount of heat required to raise the temperature of one gram of water one degree centigrade
- 1 Kilogram Calorie = 1,000 gram calories

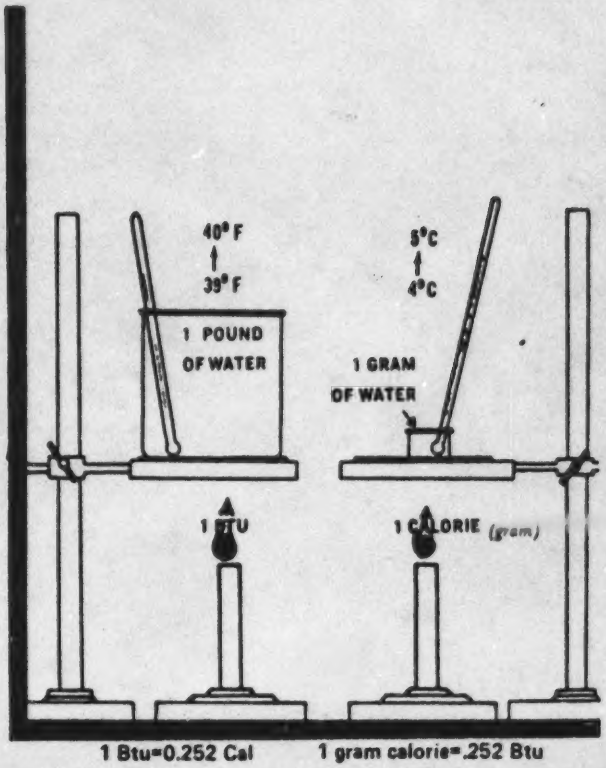


Fig. 20

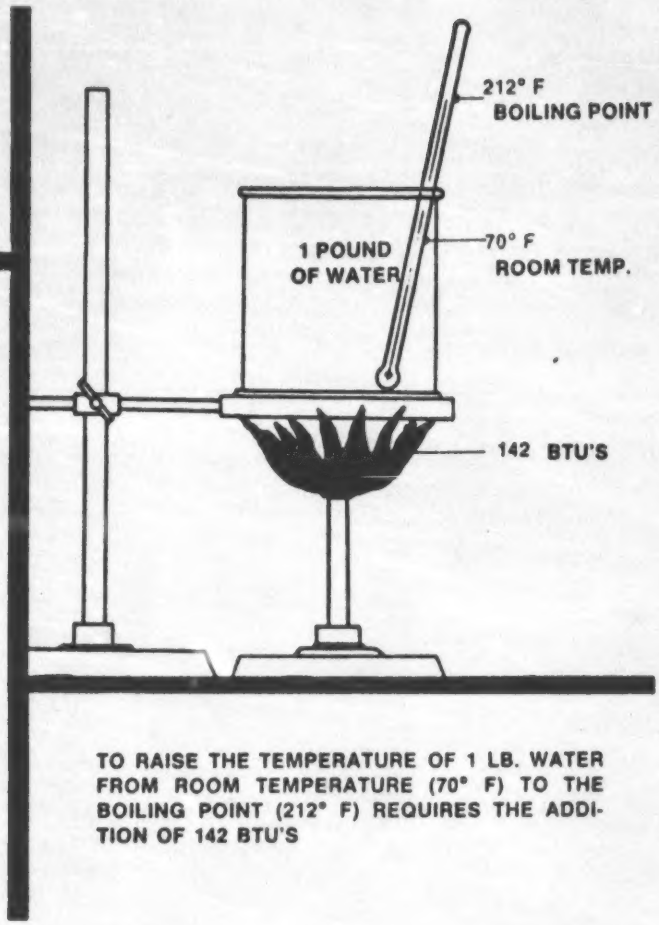
LATENT HEAT OF VAPORIZATION

THE QUANTITY OF HEAT ABSORBED BY A SUBSTANCE WHEN CONVERTED FROM:

- A SOLID TO A LIQUID
- A LIQUID TO A GAS

UNIT OF MEASURE

BTU'S PER POUND OF WATER



TO RAISE THE TEMPERATURE OF 1 LB. WATER FROM ROOM TEMPERATURE (70° F) TO THE BOILING POINT (212° F) REQUIRES THE ADDITION OF 142 BTU'S

Fig. 21-A

LATENT HEAT OF VAPORIZATION

THE QUANTITY OF HEAT ABSORBED BY A SUBSTANCE WHEN CONVERTED FROM:

- A SOLID TO A LIQUID
- A LIQUID TO A GAS

LATENT HEAT OF WATER

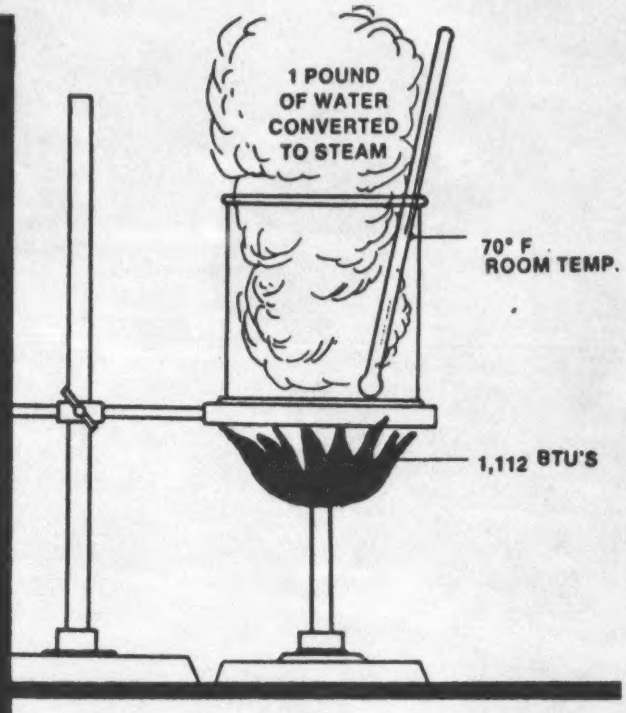
970 BTU PER POUND (APPROXIMATE)

GALLON OF WATER

WEIGHT: 8.33 POUNDS

1,112 BTU'S
x8.33
9,263 BTU'S REQUIRED TO CONVERT IT TO STEAM

WATER IS A GOOD EXTINGUISHING AGENT BECAUSE IT HAS A HIGHER HEAT OF VAPORIZATION THAN MOST SUBSTANCES



TO RAISE 1 LB. WATER FROM ROOM TEMPERATURE (70° F) TO STEAM REQUIRES THE ADDITION OF 1,112 BTU'S

Fig. 21-B

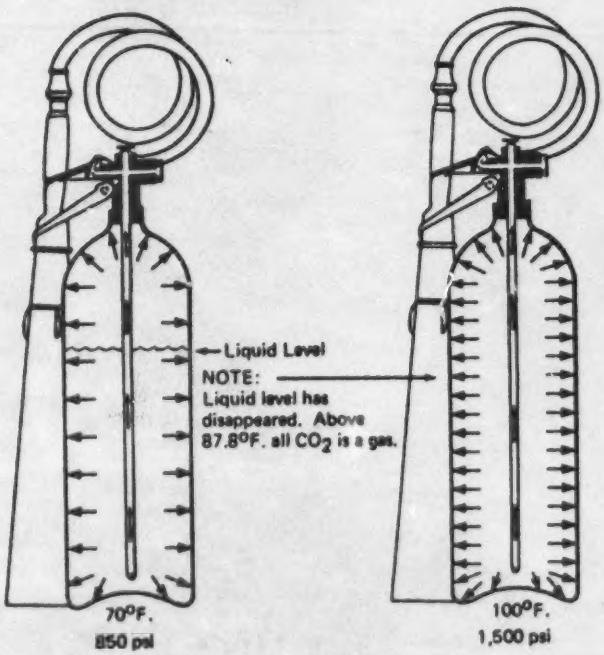

Liquid Level
NOTE:
Liquid level has disappeared. Above 87.8°F. all CO_2 is a gas.
70°F.
850 psi
100°F.
1,500 psi

Fig. 22

Much of the equipment listed below is available from your local district or can be purcahsed from chemical supply companies. In some cases other types of containers may be used or equipment built.

USE CAUTION IN ALL DEMONSTRATIONS TO PREVENT ACCIDENTS OR INJURIES

1. This demonstration consists of placing a drinking glass over a small candle to exclude air and show that a fire must have oxygen to sustain combustion.

2. Demonstrate ease of ignition by using a match or candle to ignite a large piece of wood and then wood shavings. Steel wool of a finer garde may be ignited easily.

3. Wood chips placed in a heat resistant chemistry flask and heated with a bunsen burner or propane torch will demonstrate that the vapors from the heated material will ignite.

4. Provide two 500 m.l. beakers. Place a few ounces of gasoline in one and a small amount of kerosene in the other. First ignite the gasoline to show its low flash point. Because its flash point is considerably higher it will be necessary to heat the kerosene. As it is being heated periodically attempt to ignite it. At some point the kerosene will flash and a few seconds later will continue to burn. A chemistry thermometer may be used to roughly determine flash and fire point.

5. To show relative ignition temperatures, attempt to ignite a small container of gasoline and then a container with a few ounces of Carbon Disulfide with a cigarette. Use s safety device to hold the burning cigarette.

6. If an explosion tube or box is available, flammable limits and range may be shown by using varying amounts of gasoline or other flammable liquids to illustrate lean and rich mixtures.

7. Using two containers such a 500 m.l. beakers, place a few ounces of gasoline and carbon disulfide in them. Then add a few ounces of water that has been colored with food coloring. It will then be easy to see which is heaviest, water or the flammable liquid.

8. Make a chute of sheet metal, or for a throw-away, aluminum foil. Support one end of the chute a foot or so off the table. Place several drops of gasoline on some cotton in the elevated end. At the lower end, place a lighted candle. As the vapors float downward they will ignite and flash back to the cotton showing a vapor density heavier than air.